Missouri Department of Natural Resources
Water Protection Program

Total Maximum Daily Loads (TMDLs)

for

Manacle Creek and Cedar Creek
Callaway and Boone Counties, Missouri

Completed: June 14, 2004
Approved: July 14, 2004

Two Total Maximum Daily Loads (TMDLs)
For Manacle Creek
Pollutants: Low pH and Sulfate
and
One Total Maximum Daily Load (TMDL)
For Cedar Creek
Pollutant: Sulfate


State map showing location of watershed

Name: Manacle Creek

Location: Callaway County near Stephens (north of Millersburg), Missouri

Hydrologic Unit Code (HUC): 10300102-190001

Water Body Identification (WBID): 0742

Missouri Stream Class: C[1]

Beneficial uses:

- Livestock and Wildlife Watering
- Protection of Warm Water Aquatic Life
- Protection of Human Health associated with Fish Consumption

Size of Impaired Segment: 2 miles

Legal Description of Impaired Segment: The upstream end of this segment is in Section 35, T49N, R11W and the downstream end is the mouth (where it empties into Cedar Creek) in Section 3, T48N, R11W

Pollutants: Low pH and Sulfate

Pollutant Source: Manacle Creek Abandoned Mine Lands

TMDL Priority Ranking: Medium

Name: Cedar Creek

Location: Forms the Callaway-Boone County line near Lindbergh (north of Millersburg), Missouri

Hydrologic Unit Code (HUC): 10300102-190001

Missouri Stream Class: C

[1] Class C streams may cease to flow in dry periods but maintain permanent pools that support aquatic life. See 10 CSR 20-7.031(1)(F)

Water Body Identification (WBID): 0737

Beneficial uses:

- Livestock and Wildlife Watering
- Protection of Warm Water Aquatic Life
- Protection of Human Health associated with Fish Consumption

Size of Impaired Segment: 1 mile

Legal Description of Impaired Segment: The upstream end of this segment is the mouth of Manacle Creek in Section 3, T48N, R11W and the downstream end is in Section 10, T48N, R11W

Pollutant: Sulfate

Pollutant Sources: Manacle Creek and Cross-Mitchell Abandoned Mine Lands

TMDL Priority Ranking: Medium

1. Background and Water Quality Problems

Area History[2]:

Callaway County was organized November 25, 1820, from a section of Montgomery County, directly east of Callaway. It was part of a three-way tie with Gasconade and Saline counties in being the twenty-third county organized in Missouri. Callaway County covered more than 800 square miles of land and contained 1,797 people, according to the first census taken in 1821. It was named for Captain James Callaway, who was killed in a fight with Indians near Loutre Creek. Captain Callaway was the grandson of Daniel Boone.

The first county seat was established at Elizabeth (now called Hams Prairie) where it remained for four years. Then a committee was appointed to find a more central location. In 1825, fifty acres for the future town of Fulton were purchased for $50.00 from one George Nichols. Mr. Nichols agreed to clear the timber off the spot where the courthouse was to be built. The town was originally called Volney, after a French author. There was considerable opposition to this name, however, so it was changed to Fulton in honor of Robert Fulton, inventor of the steamboat.

The people who came to Callaway County were attracted not by the glitter of gold, but by the possibility of making homes and settling their families on cheap government land. Interestingly, most settlers traveled relatively straight west from their beginnings; hence, north central Missouri (including Callaway county) was settled mainly by Virginians and Kentuckians, while the southern portion of the state was settled more by Tennesseans and Carolinians.

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[2] *Historic Callaway County 1818 to 1838* by Clyde Burch written about 1955
http://callaway.county.missouri.org/Burch.htm
Historical "Kingdom of Callaway" http://www.rootsweb.com/~mocallaw/history.html

During Civil War, Callaway County (and Missouri in general) decided that while they could not support the Union in attacking the South, they would defend their own state from Federal intervention. The governor called for an army to be raised. One of the first companies to be formed in response was from Callaway County. A Westminster student, Daniel McIntyre, was elected as captain and the company named itself the Callaway Guards. This company saw action in many places over the state, most notably in a battle on Wilson's Creek near Springfield in 1861. When they returned home, Fulton was held by the Union, so the Guard (of Southern sympathies being as they were from Virginia and Kentucky) hid out and waged guerrilla warfare until the end of the war.

Soils and Land Use:
The soils along Manacle Creek and this section of Cedar Creek are mostly Belknap silt loam and Bethesda Dumps Complex. The Belknap is nearly level bottomland with moderate permeability and slow runoff. Bethesda Dumps is the land where coal spoils have been dumped. It may have from 5-60 percent slope with slow permeability and rapid runoff. Moniteau silt loam, with slopes of 0-3 percent, is found in the narrow flood plains. It has moderate permeability with slow runoff. The uplands consist of Keswick loam and Mexico silt loam with slopes of 5-14 percent. For land use, see Appendix A.

Defining the Problem:
Manacle Creek (also called Monicle Creek[3]) is a tributary to Cedar Creek, which runs along the boundary between Boone and Callaway Counties. From 1941 to 1962, approximately 2000 acres in the Cedar Creek watershed were mined for coal by the Marriot-Reed Coal Company. The Cross-Mitchell and Manacle Abandoned Mine Lands (AMLs) were among the first to be mined, since the mining started around Interstate 70 (where they are located) and gradually worked north. The problems occurred when the coal wastes contaminated the creeks with acidic drainage. Acid mine drainage forms when sulfide minerals in rocks oxidize in the presence of water and oxygen to form highly acidic (low pH), iron- and sulfate-rich drainage. Both low pH and high levels of sulfate are harmful to aquatic life. There are many types of sulfide minerals, with pyrite and marcasite being the iron sulfides most common in coal regions. These minerals make up a large amount of the overburden (rock and soil above the coal seams) in the Manacle Creek/Cedar Creek area. See Appendix B for a map of the creeks with sampling sites.

There were three main sites where coal was mined around these creeks. The 24-acre Tipple[4] site contained abandoned coal waste slurry fines material from the washing operation that was conducted on the site. The slurry material had been deposited in four excavated or diked areas that ranged from a few feet to 15-50 feet deep. Acidic runoff was directed from the site to a tributary of Manacle Creek.

Mining at the 81-acre Cross-Mitchell site, where Manacle Creek joins Cedar Creek, drastically changed the course of Cedar Creek through that area. The final cut became a 9-acre lake containing acid water with spoil banks of mixed coal material on the northwest side of it. The heavier "gob" waste material from the washing operation at the Tipple site was deposited on

[3] Depending on which map is used (USGS topographic map, Conservation Atlas county map, county soil survey map), there is a lot of discrepancy in the name of this creek and even which branch is the creek and which is a tributary. The segment on the 303(d) list (Manacle) is consistent with Missouri's Water Quality Standards and the Soil Survey of Callaway County, Missouri map –Sheets # 10 and 11.
[4] Cross-Mitchell and Tipple Reclamation Project, Summary, pV-1. Booker Associates, Inc., St. Louis, Missouri

19 acres at the eastern end of the Cross-Mitchell site. For several years [before 1981] a municipal landfill operated on a 20-acre area north of the lake and a 28-acre area south of the lake.

In 1985, a reclamation project of the Cross-Mitchell and Tipple areas was completed near the juncture of I-70 and Cedar Creek. One hundred and five acres were reclaimed at a cost of $1.4 million. The third area where mining affected these two creeks was the Manacle Creek AML area, one mile north of I-70. A reclamation of the 197 acres in this area was completed in 1988 at a cost of $1.03 million. These projects were accomplished mainly by re-contouring the surface of the land, eliminating acid ponds, burying acid-forming spoils and establishing permanent vegetation. In areas of concentrated coal wastes, a six-inch layer of lime was applied (under 18 inches of impermeable clay) prior to the placement of topsoil to help neutralize the acid-forming materials underneath. In spite of all this work, the creeks still occasionally exceed water quality standards. The problem is that acid drainage is seeping into the creeks from underground mines. Neither the technology nor the funds presently allow for this to be remedied further.

Data collected from 2000-2003 show that the pH and sulfate levels are much improved since the reclamations were completed. In fact, the creeks have not exceeded water quality standards since early 2001(Data, Appendix C). However, it is unknown why this is so since nothing has been done since the reclamations in 1988 to account for these results. It could be just the time of year that the samples have been collected and that the pH and sulfate will exceed limits in the future. The department plans to continue monitoring the sites into the foreseeable future.

2. Description of the Applicable Water Quality Standards and Numeric Water Quality Target

Beneficial Uses:
The beneficial uses of Manacle and Cedar creeks, WBID 742 and 737 respectively, are:

- Livestock and Wildlife Watering
- Protection of Warm Water Aquatic Life
- Protection of Human Health associated with Fish Consumption

Use That is Impaired:
Protection of Warm Water Aquatic Life

The Limited Warm Water Fishery classification applies to these prairie streams (See footnote 2 on page 1). The stream classifications and designated uses may be found at 10 CSR20-7.031(1)(C) and Table H.

Anti-degradation policy:
Missouri's Water Quality Standards include the Environmental Protection Agency (EPA) "three-tiered" approach to anti-degradation, and may be found at 10 CSR 20-7.031(2).

Tier I defines baseline conditions for all waters and requires that existing beneficial uses are protected. TMDLs would normally be based on this tier, assuring that numeric criteria (such as dissolved oxygen and ammonia) are met to protect uses.

Tier II requires that no degradation of high-quality waters occur unless limited lowering of quality is shown to be necessary for "economic and social development." A clear implementation policy for this tier has not been developed, although if sufficient data on high-quality waters are available, TMDLs could be based on maintaining existing conditions, rather than the minimal Tier I criteria.

Tier III (the most stringent tier) applies to waters designated in the water quality standards as outstanding state and national resource waters; Tier III requires that no degradation under any conditions occurs. Management may prohibit discharge or certain polluting activities. TMDLs would need to assure no measurable increase in pollutant loading.

This TMDL will result in the protection of existing beneficial uses, which conforms to Missouri's Tier I anti-degradation policy.

Specific Criteria:
pH Standards:
Missouri's Water Quality Standards (WQS), 10 CSR20-7.031 Section (4)(E), states that water contaminants shall not cause pH to be outside of the range of 6.5-9.0 Standard Units (SU).

Sulfate Standards:
Sulfate and chloride are linked together in the WQS. Section (4)(L)1 only concerns streams with 7Q10 low flow[5] of less than one cubic foot per second (cfs). Here it states that the concentration of sulfate plus chloride ($S0_4$ + Cl) shall not exceed 1000 milligrams per liter (mg/L) for protection of aquatic life.

<u>Impairments</u>

Manacle Creek	2.0 miles pH and sulfate
Cedar Creek	1.0 mile sulfate

Numeric Water Quality Target:
The most severe episodes of acidity (low pH) and high levels of sulfate occur during low flow conditions when there is little or no upstream flow to dilute the drainage from these abandoned mine lands. For this reason the critical flow condition for this TMDL is the 7Q10 low flow (footnote 5).

<u>Numeric Water Quality Target for Sulfate</u>: Sulfate and chloride criteria for the protection of aquatic life are linked in Missouri's Water Quality Standards. Manacle and Cedar Creeks each have a 7Q10 low flow of less than one (1) cubic foot per second, therefore the in-stream concentration of chloride plus sulfate in each creek shall not exceed one thousand milligrams per liter (1000 mg/l), as per the standard stated above.

<u>Numeric Water Quality Target for pH</u>: The pH target for Manacle Creek is 6.5 SU. pH is the expression of hydrogen ion activity in water and is highly dependent on chemical reactions that consume or produce hydrogen ions. In natural waters these chemical reactions determine the

[5] 7Q10 is the lowest average flow for seven consecutive days with a recurrence interval of ten years.

assimilative "buffering" capacity of the solution to neutralize additional acidity or alkalinity. Therefore, for TMDL loading purposes, a secondary numeric water quality target of alkalinity is also being required to ensure the pH will not be below 6.5 SU in Manacle Creek. Missouri calculates the total alkalinity target to be 40 mg/L or greater year round (see Margin of Safety, Section 6),

3. Loading Capacity

The Loading Capacity (LC) is the greatest amount of pollutant loading that a stream can assimilate without becoming impaired. It is equal to the sum of the Load Allocation (LA), the Wasteload Allocation (WLA) and the Margin of Safety (MOS) and can be expressed as an equation:

$$\mathbf{LC = LA + WLA + MOS}$$

Dry weather critical flow from the Manacle Creek and the Cross-Mitchell AML can not be accurately determined because surface flow and seepage rates from this area are variable. These creeks are Class C streams, which cease to flow in dry periods but maintain permanent pools that support aquatic life. Dry weather critical flow is therefore 0.1 cfs or less. Since there can be minimal upstream dilution during dry weather conditions, the flow of water coming from these AML areas will have to meet in-stream water quality standards for pH (6.5-9.0 SU) and an alkalinity of 40.0 mg/L or more. Neither the pH nor the alkalinity concentrations used as the numeric TMDL endpoints can be summed as Load Allocations (LAs) + Wasteload Allocations (WLAs) + Margin of Safety (MOS). The standard Load Capacity equation shown above is not applicable when calculating pH and concentration based endpoints.

Sulfate:
For sulfate, load capacity is the combined sulfate plus chloride standard of 1000 mg/L. Using the numeric water quality target and a margin of safety of four percent (4%), or 40 mg/L (see Section 6), an in-stream sulfate plus chloride target of 960 mg/L should ensure that water quality standards are met and maintained in Manacle and Cedar Creeks.

pH:
For pH expressed as Standard Units (SU) in the abandoned mine drainage, the concentration-equivalent load capacity is a pH of 6.5-9.0 SU (the state water quality standard). To ensure that the pH water quality standard is met and maintained in Manacle Creek, the alkalinity target is set at 40.0 mg/L or greater year round.

4. Load Allocations (Nonpoint Source Load)

Load Allocation (LA) is the maximum allowable amount of the pollutant that can be assigned to nonpoint sources.

Sulfate:
All discharges to the stream are to be at or below 960 mg/L sulfate plus chloride under all flow conditions, thereby ensuring that the numeric in-stream water quality standard will be met and maintained in Manacle and Cedar creeks.

pH:
Since the load capacity for Manacle Creek is concentration based, discharges to the stream will be required to meet the 40 mg/L alkalinity target. This target will allow the standard of 6.5 to 9.0 SU be met.

5. Wasteload Allocation (Point Source Load)

The Wasteload Allocation (WLA) is the maximum allowable amount of the pollutant that can be assigned to point sources. There are presently no point source discharges that would impact acidity or sulfate in Manacle Creek or to the affected segment of Cedar Creek; therefore, the WLA is zero for sulfate. Since the pH cannot be expressed as a load, the "WLA" for pH is simply that there be no deviation from the standard.

Any future discharges would be required by a Missouri State Operating Permit to maintain a pH in the range of 6.5 – 9.0 SU, a chloride plus sulfate concentration of 960 mg/L and a secondary requirement for a total alkalinity of 40 mg/L.

6. Margin of Safety (MOS)

A Margin of Safety (MOS) is required in the TMDL calculation to account for uncertainties in scientific and technical understanding of water quality in natural systems. The MOS is intended to account for such uncertainties in a conservative manner. Based on EPA guidance, the MOS can be achieved through one of two approaches:

(1) Explicit - Reserve a portion of the loading capacity as a separate term in the TMDL.
(2) Implicit - Incorporate the MOS as part of the critical conditions for the waste load allocation and the load allocation calculations by making conservative assumptions in the analysis.

MOS for Sulfate:
Insufficient sulfate, chloride, and other data exist to establish how much uncertainty exists in the linkage between a sulfate-plus-chloride allocation and the water quality in Manacle and Cedar creeks. As a result, an explicit MOS equal to a percent reduction of the loading capacity will be used. It was calculated as follows:

Using the mean chloride concentration found in Manacle Creek (14.6 mg/L) and Cedar Creek (15.4 mg/L), a conservative in-stream allocation for chloride of two percent (20 mg/L) is appropriate. No other significant sulfate plus chloride sources exist within the watershed, therefore a two percent (2%) allocation to account for these uncertainties is reasonable. Adding these together, a margin of safety equal to a four percent (4%) reduction of the loading capacity has been selected. That calculates out to a 40 mg/L ($S0_4$ + Cl) reduction:

$$0.04*1000 \text{ mg/L} = 40 \text{ mg/L}$$

With a MOS of 40 mg/L, the in-stream target for $S0_4$ + Cl equals 960 mg/L for Manacle and Cedar Creeks. If future in-stream monitoring indicates applicable water quality standards are exceeded, the TMDL will be reopened and the MOS re-evaluated based on additional data.

MOS for pH:
Manacle Creek is also impaired for pH. As stated before, the pH criterion alone may not provide sufficient assurance that the proper pH range will be maintained in Manacle Creek. This is due

to possible latent acidity. Net alkalinity is the preferred secondary water quality target because it may be treated as a conservative constituent. However, the lack of acidity data for the site makes a statistical analysis of net alkalinity difficult. Review of data from this site and nearby Upper Cedar Creek, (which is similar), suggests that total acidity will not be significant at higher total alkalinity values. Thus, total alkalinity is a good approximation of net alkalinity in Manacle Creek. Moreover, alkalinity is a measurable characteristic in Manacle Creek and can be linked to the pH water quality criterion. Alkalinity has units of mg/L as $CaCO_3$ (calcium carbonate) as discussed in Standard Methods for the Examination of Water and Wastewater.

An Ordinary Least Squares (OLS) approach was used to calculate a regression line and associated statistics for Manacle Creek (Appendix D) using the pH and alkalinity values found in Appendix C. Alkalinity standard residuals were computed, plotted and examined for outliers. There were no outliers (data with standard residual values greater than ± 3.0), so all of the data from 1997 to 2003 were used. Residuals were also tested for normality and found to adhere to a normal distribution. The predicted alkalinity associated with a pH of 6.5, with a confidence interval of 95 percent, would be 27.7 mg/L alkalinity ± 12.5 mg/L alkalinity. Choosing the upper confidence limit of +12.5 mg/L alkalinity as the margin of safety, an in-stream target of 40 mg/L alkalinity (27.7 mg/L + 12.5 mg/L = 40.2 rounded to 40 mg/L) should ensure adequate buffering to prevent in-stream pH values from dropping below 6.5.

7. Seasonal variation

The water quality data collected to this point represents all seasons. While the critical condition is during periods of low flow, the LA and TMDL (expressed as concentrations) are applicable at all flow conditions, hence all seasons. Also, the primary processes involved in the formation of acid water and the oxidation of sulfide are not significantly impacted by differences in air and water temperatures associated with seasonal change. Therefore, Missouri standards do not distinguish between summer and winter for sulfate and pH.

8. Monitoring Plan for TMDLs Developed Under the Phased Approach

Manacle Creek and Cedar Creek at I-70 are presently included in the department's continuous monitoring plan. The Northeast Regional Office (NERO) samples them twice a year for a variety of stated parameters.

Organization	Monitoring Type	Waterbody Name	Status	Fld	Mi	Comments
MDNR	Ambient (NERO)	Manacle Creek NWNWSW2,48,11	Ongoing	2	2	Chloride, Sulfate, Alkalinity/acidity, Flow
MDNR	Ambient (NERO)	Cedar Creek @I-70	Ongoing	2	2	Chloride, Sulfate, Alkalinity/acidity, Flow

The number in the boxes is the frequency or how many times monitoring will be done per year. The headings are defined as follows:

Fld – Field Measurements. These are measurements made in the field and include water temperature, pH and specific conductance for these two sites.

Mi -- Major ions and allied measurements. These include chemical analysis for calcium, magnesium, sulfate, chloride and bicarbonate and determination of alkalinity/acidity. The analytes for these sites are listed in the Comments column.

9. Implementation Plans

Prior reclamation projects in Manacle and Cedar creeks have already cost more than $2.4 million. It is possible that wetland cells could be constructed to treat underground water seeps, as has been done in the Upper Cedar Creek area and other abandoned mine land sites around the state. However, these projects are very expensive, and wetland cells would have to be constructed in many locations to handle acidic underground flows. As with most reclamations, the projects already completed have remedied the majority of the problems, maybe as much as 95 percent. The last five percent or so is the hardest and will likely cost more money that the first 95 percent altogether. Implementation of any further reclamation work will be addressed as future technology advances are made and program funding allows.

The alkalinity vs. pH regression model will be rerun in 2006 with the new data collected in 2004 and 2005 to determine whether the trend is toward meeting water quality standards. This TMDL will be incorporated into Missouri's Water Quality Management Plan.

10. Reasonable Assurances

The department's Water Protection Program will continue low-flow water chemical monitoring of the impaired segments of Manacle and Cedar creeks. Periodic review of the department's Water Quality Management Plans and monitoring data should provide reasonable assurance that Manacle and Cedar Creek will meet water quality standards. If this monitoring reveals that water quality standards are not being met for pH (6.5 to 9.0 SU) or sulfate plus chloride (1000 mg/L or less), or the numeric target is not being met for alkalinity (40 mg/L or more), then these TMDLs will be re-opened and re-evaluated.

11. Public Participation

These water quality limited segments of Manacle and Cedar creeks are included on the approved 2002 303(d) list for Missouri. The Missouri Department of Natural Resources' Water Protection Program developed these TMDLs.

After the department develops a TMDL, it is sent to EPA for examination and then the edited draft is placed on public notice. The public notice period for the draft Manacle and Cedar Creeks TMDL was from April 23 to May 23, 2004. Groups receiving the public notice announcement included the Missouri Clean Water Commission, the Water Quality Coordinating Committee, the TMDL Policy Advisory Committee, Callaway County Soil and Water Conservation District, Stream Team volunteers in the watershed (46), the appropriate legislators (5) and others that routinely receive the public notice of Missouri State Operating Permits. Copies of the notice, the two comments received and the department responses are in the Manacle Creek/Cedar Creek file.

12. Administrative Record and Supporting Documentation

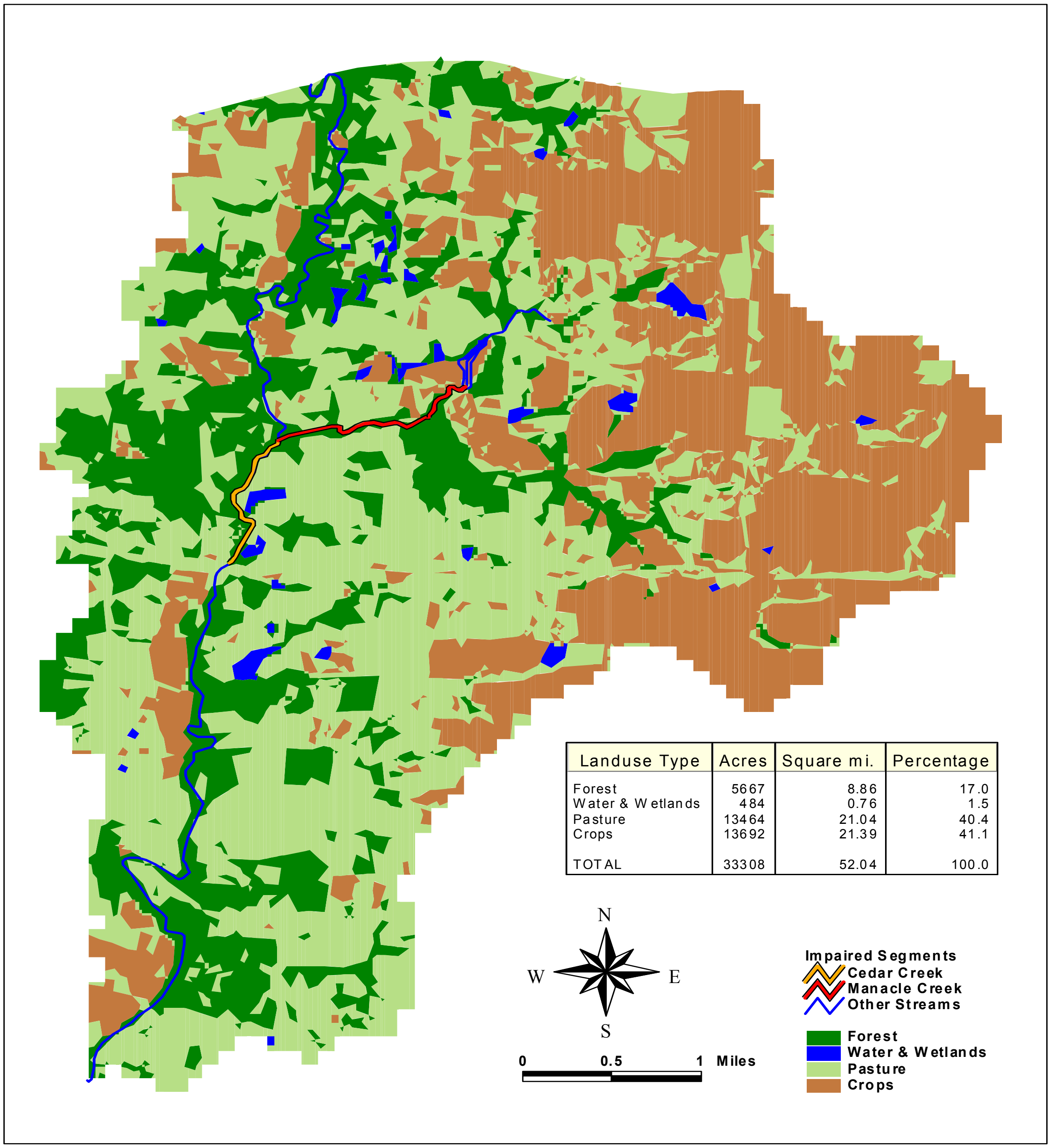
An administrative record on the Manacle and Cedar Creeks TMDL has been assembled and is being kept on file with the Missouri Department of Natural Resources, including the following:

A brief report and a photo file of the reclamation projects
Manacle and Cedar Creeks TMDL Information Sheet
Public Notice announcement
Public comments and the department's responses

13. Appendices

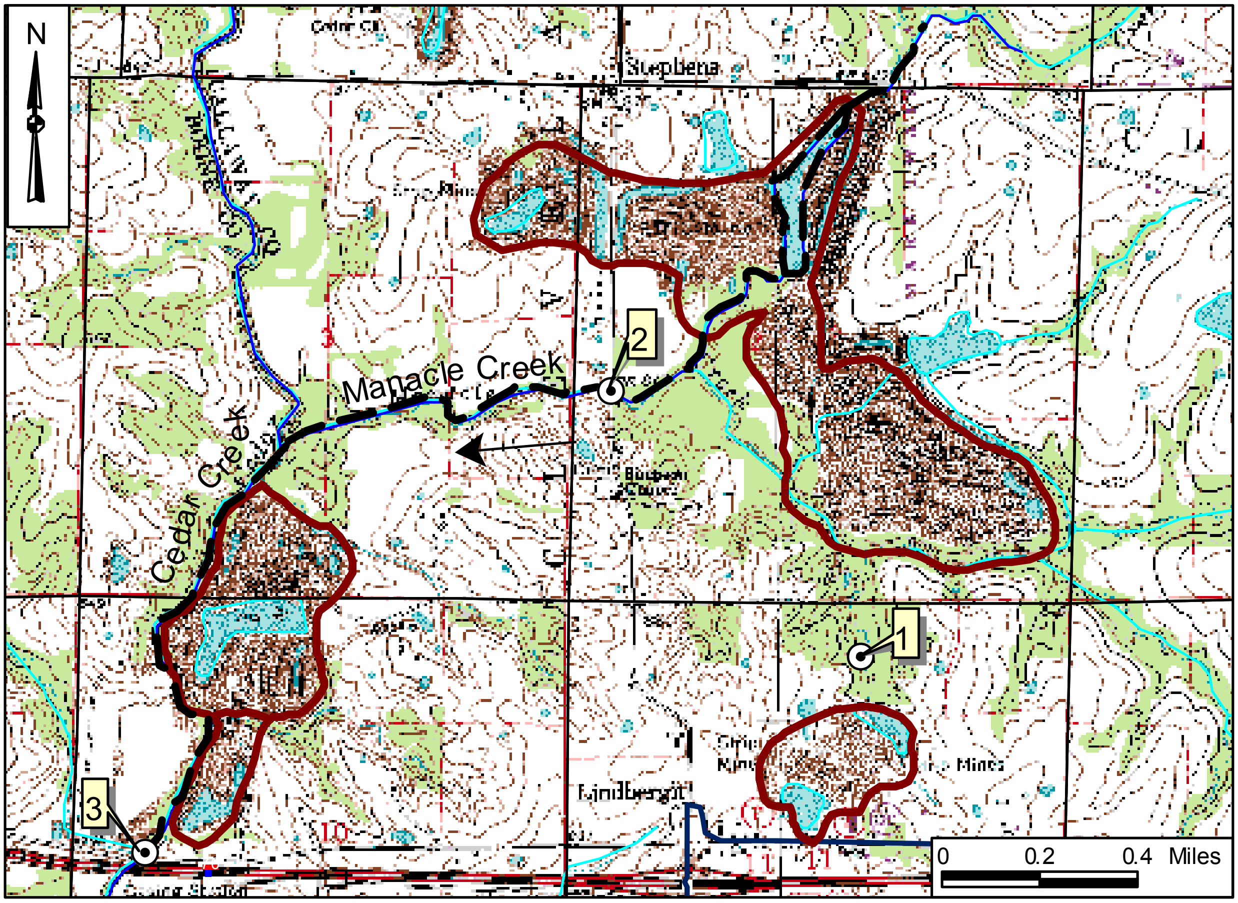
Appendix A – Land use map for Manacle Creek-Cedar Creek watershed
Appendix B – Topographic map showing sampling sites and impaired segments
Appendix C – Pre- and Post-Reclamation Data
Appendix D – The relationship of pH and total alkalinity in Manacle Creek using the Ordinary Least Squares (OLS) approach – graphs and statistics

Appendix A
Land Use in Manacle Creek and Cedar Creek (middle) Watersheds



Landuse Type	Acres	Square mi.	Percentage
Forest	5667	8.86	17.0
Water & Wetlands	484	0.76	1.5
Pasture	13464	21.04	40.4
Crops	13692	21.39	41.1
TOTAL	33308	52.04	100.0

Appendix B
Topographic map of Manacle Creek and part of Cedar Creek showing sampling sites and impaired segments



Index of Sampling Sites
1 – Tributary from reclaimed slurry pond
2 – Manacle Creek 0.5 mile south of Stephens
3 – Cedar Creek at Interstate 70

Appendix C - Data
Table 1. Manacle and Cedar Creek Pre-reclamation Data

Org	Site	Site Name	Yr	Mo	Dy	Flow	pH	SC	Alk	Acid	SO4	Cl
Envirodyne	1	Trib. From Reclaimed Slurry Pond	1981	7	30	3.1	5.6		0	158	387	
Envirodyne	1	Trib. From Reclaimed Slurry Pond	1981	8	27	0.01	3.6		0	313	1347	
Envirodyne	1	Trib. From Reclaimed Slurry Pond	1981	9	28	0	2.9		0	1095	29.2	
Envirodyne	1	Trib. From Reclaimed Slurry Pond	1981	10	26	0.01	3		0	1200	2387	
Envirodyne	1	Trib. From Reclaimed Slurry Pond	1981	11	22	0.1	2.9		0	486	1885	
Envirodyne	1	Trib. From Reclaimed Slurry Pond	1981	12	28	0.01	3.7		0	558	993	
Envirodyne	1	Trib. From Reclaimed Slurry Pond	1982	2	24	2.6	5.9		22	54	199	
Envirodyne	1	Trib. From Reclaimed Slurry Pond	1982	3	24	2.1	5		0	158	474	
Envirodyne	1	Trib. From Reclaimed Slurry Pond	1982	4	27	0.4	3.3		0	182	688	
Envirodyne	1	Trib. From Reclaimed Slurry Pond	1982	5	24	0.9	4.3		0	299	685	
Envirodyne	1	Trib. From Reclaimed Slurry Pond	1982	6	21	0.23	2.9		0	253	630	
MDNR	1	Trib. From Reclaimed Slurry Pond	1991	4		0.3	7.1	480				
Envirodyne	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	1981	7	30	5.61	5.8		0	76	340	
Envirodyne	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	1981	8	27	1.12	6.3		0	98.2	779	
Envirodyne	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	1981	9	28	0	3.7		0	1002	3390	
Envirodyne	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	1981	10	26	0.01	3.2		0	564	1882	
Envirodyne	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	1981	11	22	0	3.2		0	1146	1330	
Envirodyne	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	1981	12	28	0.9	3.6		0	506	1394	
Envirodyne	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	1982	1	25	0.01	5.1		0	124	412	
Envirodyne	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	1982	2	24	6.8	4.8		2	64	305	
Envirodyne	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	1982	3	24	3.1	4.7		0	136	562	
Envirodyne	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	1982	4	27	0.4	3.5		0	168	1045	
Envirodyne	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	1982	5	24	2.1	4.3		0	149	525	
Envirodyne	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	1982	6	21	1.38	3.7		0	58	400	
MDNR	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	1991	4		0.4	6.8	720				
MDNR	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	1992	3		0.4	6.5	1100				
MDNR	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	1995	12		0.05	5.2	2530				

Abbreviations and units of measurement:
Flow is reported in cfs; pH in SU; SC=Specific Conductivity in µS/cm; Alk=Alkalinity in mg/L; Acid=Acidity in mg/L; SO4= Sulfate in mg/L; Cl=Chloride in mg/L

Org	Site	Site Name	Yr	Mo	Dy	Flow	pH	SC	Alk	Acid	SO4	Cl
Envirodyne	3	Cedar Cr. @I-70	1981	7	30	34	6.7		14	20	316	
Envirodyne	3	Cedar Cr. @I-70	1981	8	27	6.5	4.4		0	53.8	746	
Envirodyne	3	Cedar Cr. @I-70	1981	9	28	0.01	3.8		0	63	1867	
Envirodyne	3	Cedar Cr. @I-70	1981	10	26	1.04	3.7		0	122	1148	
Envirodyne	3	Cedar Cr. @I-70	1981	11	22	3.11	4.6		0	99	770	
Envirodyne	3	Cedar Cr. @I-70	1981	12	28	3.2	4.3		0	190	1140	
Envirodyne	3	Cedar Cr. @I-70	1982	1	25	0.01	6		26	8	193	
Envirodyne	3	Cedar Cr. @I-70	1982	2	24	68.3	6.4		16	36	194	
Envirodyne	3	Cedar Cr. @I-70	1982	3	24	15.7	6.7		15	16	389	
Envirodyne	3	Cedar Cr. @I-70	1982	4	27	5.1	4.6		8	92	740	
Envirodyne	3	Cedar Cr. @I-70	1982	5	24	11.6	5.5		18	5	375	
Envirodyne	3	Cedar Cr. @I-70	1982	6	21	0.01	4.2		2	62	250	

Table 2. Manacle and Cedar Creek Post-reclamation Data

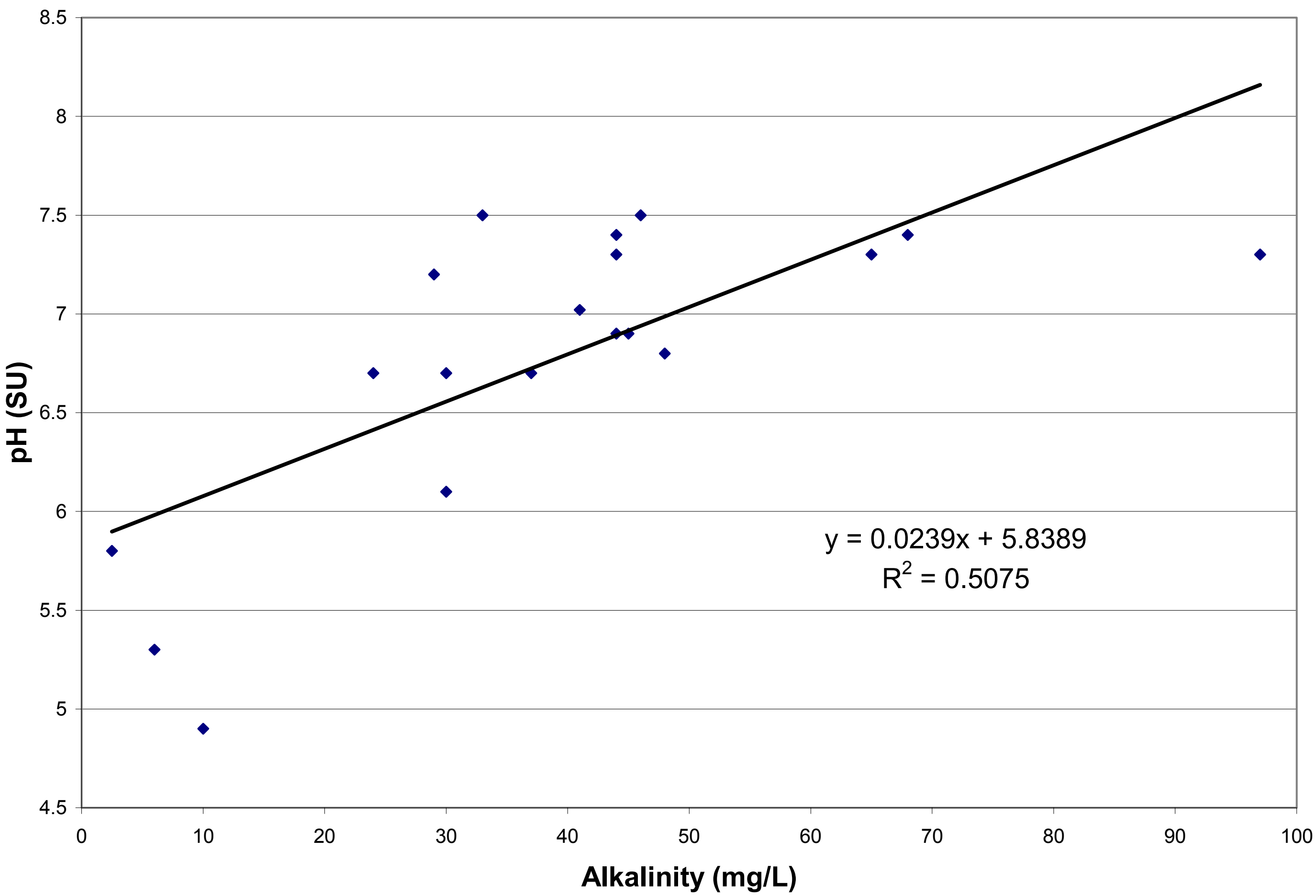
Org	Site	Site Name	Yr	Mo	Dy	Flow	pH	SC	Alk	Acid	SO4	Cl	SO4 +Cl
MDNR	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	1997	7		0.6	6.7	683	37		280	6	286
MDNR	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	1997	10		0	6.2	1925					
MDNR	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	1998	4	20	0.6	6.9	722					
MDNR	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	1998	7	21		6.9	1080	44		568		
MDNR	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	1998	8	6		6.9	890	45		368		
MDNR	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	1998	9	9		7.3	995	97		411		
MDNR	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	2000	3	30		7.5	650	33		345	16	361
MDNR	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	2000	4	25		4.9	1640	10	0	1300	13	1313
MDNR	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	2000	9	28		6.8	655	48	0	305	9	314
MDNR	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	2000	12	27		5.8	1810	2.5	35	1190	11	1201
MDNR	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	2001	3	29		6.7	973	30	2.5	506	11	517
MDNR	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	2001	6	27		6.7	1080	24	2.5	512	5	517
MDNR	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	2001	9	5		7.3	918	44	2.5	439	17	456
MDNR	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	2001	10	30		6.1	1460	30	2.5	782	14	796
MDNR	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	2001	12	31		5.3	2390	6	38	50	26	76
MDNR	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	2002	2	5		7.5	849	46	2.5	355	14	369
MDNR	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	2002	3	21		7.2	1400	29	12	659	26	685
MDNR	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	2002	6	18		7	620	41	2.5	281	8.2	289
MDNR	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	2002	10	8		7.3	561	65	2.5	222	13	235
MDNR	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	2003	4	2		7.4	871	44	2.5	411	33	444
MDNR	2	Manacle Cr. 0.5 mi. S. of Stephens,Mo.	2003	9	16		7.4	871	44	2.5	256	11.6	268

Org	Site	Site Name	Yr	Mo	Dy	Flow	pH	SC	Alk	Acid	SO4	Cl	SO4 +Cl
USGS	3	Cedar Cr. @I-70	1990	10	11	13	7.2	644	39	0.01	210	29	239
USGS	3	Cedar Cr. @I-70	1990	11	13	0.55	**6.3**	1320	30	0.4	810	9.9	820
USGS	3	Cedar Cr. @I-70	1990	12	11	4.8	6.8	771	37	0.2	330	13	343
USGS	3	Cedar Cr. @I-70	1991	1	9	3.9	7.3	760	44	0.01	59	7.5	67
USGS	3	Cedar Cr. @I-70	1991	2	5	60	7.2	268	40	0.01	59	7.5	67
USGS	3	Cedar Cr. @I-70	1991	3	11	2.6	7.6	878	62	0.3	340	13	353
USGS	3	Cedar Cr. @I-70	1991	4	2	2.7	7	903	55	0.2	400	9	409
USGS	3	Cedar Cr. @I-70	1991	5	15	20	7.2	549	59	0.2	230	4.1	234
USGS	3	Cedar Cr. @I-70	1991	6	13	0.94	6.8	1000	77	0.4	530	12	542
USGS	3	Cedar Cr. @I-70	1991	7	16	0.08	7.1	1230	73	0.1	590	13	603
USGS	3	Cedar Cr. @I-70	1991	8	14	0.01	7	1680	82	0.3	970	29	999
USGS	3	Cedar Cr. @I-70	1991	9	5	0.06	7.1	1410		0.01	970	29	999
MDNR	3	Cedar Cr. @I-70	1992	3		2.2	6.8	1200					
MDNR	3	Cedar Cr. @I-70	1995	12			7.2	1250					
MDNR	3	Cedar Cr. @I-70	1998	7	21		7.1	790	76	0	329		
MDNR	3	Cedar Cr. @I-70	1998	8	6		7.1	525	62	0	221		
MDNR	3	Cedar Cr. @I-70	1998	9	9		7.3	1150	92	0	529		
MDNR	3	Cedar Cr. @I-70	2000	3	30		7.4	840	43		501	13	514

MDNR	3	Cedar Cr. @I-70	2000	4	25		6.7	1180	78	0	722	23	745
MDNR	3	Cedar Cr. @I-70	2000	9	28		6.9	1020	62	0	549	10	559
MDNR	3	Cedar Cr. @I-70	2000	12	27		7.1	1245	86	2.499	622	15	637
MDNR	3	Cedar Cr. @I-70	2001	3	29		7.2	720	73	2.499	290	11	301
MDNR	3	Cedar Cr. @I-70	2001	6	27		6.8	805	78	2.499	23	10	33
MDNR	3	Cedar Cr. @I-70	2001	9	5		7.1	791	98	2.499	307	14	321
MDNR	3	Cedar Cr. @I-70	2001	10	30		7.1	629	79	2.499	218	14	232
MDNR	3	Cedar Cr. @I-70	2001	12	31		6	1370	83	2.499	442	21	463
MDNR	3	Cedar Cr. @I-70	2002	2	5		7.4	631	51	2.499	194	12	206
MDNR	3	Cedar Cr. @I-70	2002	3	21		7.3	873	63	2.499	338	18	356
MDNR	3	Cedar Cr. @I-70	2002	6	18		7.1	584	66	2.499	229	8	237
MDNR	3	Cedar Cr. @I-70	2002	10	8		7.2	520	80	2.499	184	10	194
MDNR	3	Cedar Cr. @I-70	2003	4	2		7.4	825	70	2.499	347	26	373
MDNR	3	Cedar Cr. @I-70	2003	9	16		7.4	454	80	2.499	122	8	130
Note: Values of 2.499 represent a lab reported value of “less than 5” as the analysis result													

Appendix D
Ordinary Least Squares (OLS) approach used to calculate a regression line and associated statistics

Figure 1. Relationship between pH and Alkalinity in Manacle Creek 1997-2003



<u>Regression Analysis</u>

Mean pH	6.775
Mean Alkalinity	39.132
Sum of Squares (x^2 = Alkalinity)	8914.994
Sum of Squares (y^2 = pH)	10.047
Sum of Squares (xy = Alkalinity and pH)	213.204
Pearson Correlation Coefficient	0.712
Regression Slope	0.0239
Mean Square Error	0.291
Standard Error of the Regression	0.539

SUMMARY OUTPUT

Ordinary Least Squares (OLS) Analysis
Manacle Creek, Callaway County, Missouri
Using data from 1997-2003

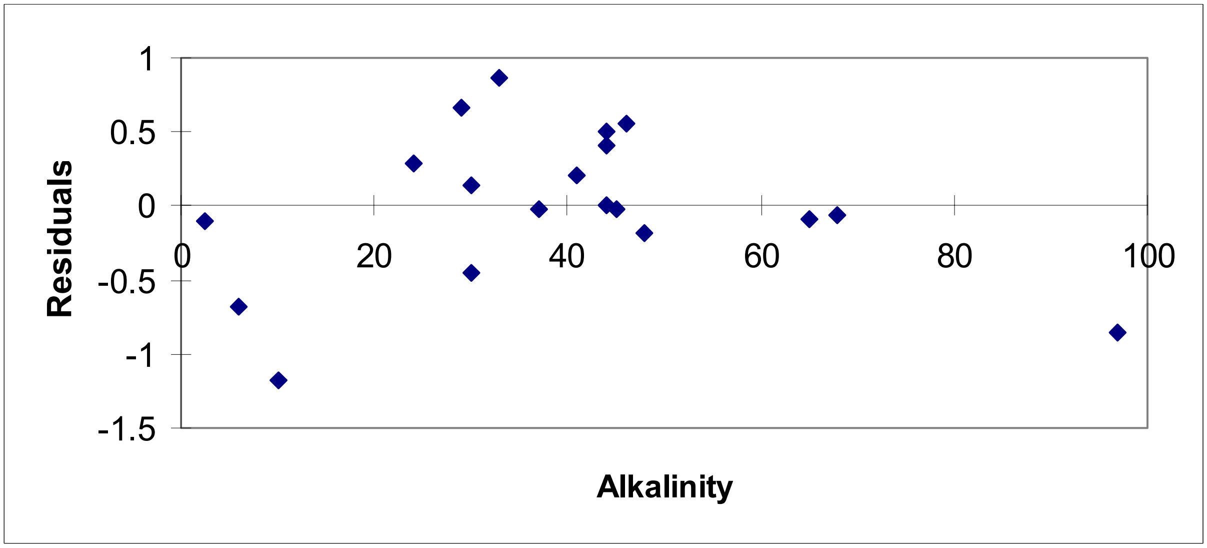
Regression Statistics	
Multiple R	0.71241422
R Square	0.50753402
Adjusted R Square	0.47856544
Standard Error	0.53946858
Observations	19

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	5.098825704	5.098825704	17.52015126	0.000620472
Residual	17	4.94744798	0.291026352		
Total	18	10.04627368			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	5.83889742	0.255548563	22.84848465	3.36121E-14	5.299736328	6.37805851
X Variable 1	0.02391523	0.005713545	4.185707976	0.000620472	0.011860687	0.03596977

Figure 2. Alkalinity Residual Plot for OLS Analysis for Manacle Creek



This graph shows that all data were within ± 3 mg/L. There were no outliers, so all data (from 1997-2003) were used in the regression.

Figure 3. Normality Plot for Manacle Creek